Chapter 16

Presentation Graphics

The data are collected, the analyses performed, the conclusions drawn, and now the results must be presented to one or more audiences. Whether by oral presentations or written reports, more information can be quickly conveyed using graphs than by any other method. A good figure is truly worth a thousand table entries.

For oral presentations, rarely are tables effective in presenting information. Listeners are not familiar with the data, and have not poured over them for many hours as has the presenter. Numbers are often not readable further back than the second row. Instead, speakers should take the time to determine the main points to be illustrated, and construct a figure from the data to illustrate those points prior to the presentation. This both shows courtesy to the listeners, and convinces them that the data do provide evidence for the conclusions the speaker has reached.

In a written report, major conclusions are usually listed at the end of the final section, or at the front in an executive summary. A figure illustrating each major conclusion should be contained somewhere in the report. The reader should be able to quickly read an abstract, look at the figures, and have a good idea of what the report is about. Figures should be a "visual abstract" of the report, and are one of the best ways to convince someone to take enough time to read your work. They again give evidence that the data do support the conclusions you have reached.

All graphs are not created equal. Some present quantitative information clearly and precisely. Others are not as effective, and may even be misleading. Guidelines to the "level of precision" for common types of graphics are presented in this chapter. Also presented are a collection of misleading graphics which should be avoided. These come largely from experience, driven by the impression that their use is becoming more common in graphics software on microcomputers.

Understanding the strengths and weaknesses of various types of graphs is important when choosing the most appropriate way to present data. Three references stand out in their evaluation of graphs for quantitative data: Cleveland (1985) discusses the ability of the human eye-brain system to process information. Tufte (1983) describes the artistry involved in creating graphics. Schmid (1983) is a handbook listing numerous examples of both good and bad graphics. This chapter draws on ideas from these three and others.

16.1 The Value of Presentation Graphics

Graphs can clarify complex interrelationships between variables. They can picture the "signal" over and above the "noise", letting the data tell its story. In Chapter 2, graphs for understanding data were discussed. These same methods which provide insight to an investigator will also illustrate important patterns and contrasts to an investigator's audience.

Tables simply do not allow easy extraction of a data signal. For example, Exner and Spalding (1976) and Exner (1985) determined concentrations of nitrate in about 400 wells in the Central Platte region of Nebraska ten years apart -- in 1974 and 1984. As little information is available about changes in groundwater quality over time, these are important studies. Data were displayed with maps and tables for each separate period. Comparisons between the periods were done as narrative text, relying on the tables and maps. To better illustrate these data, lowess smooths of nitrate concentration versus depth for the two time periods are shown in Figure 16.1. This concise figure effectively illustrates the increases in nitrate at a given depth over the ten year period, and the decrease in concentration with depth. It shows that increases in concentration over the 10 years are much larger at shallow depths. For a specific nitrate "action level" such as 8 mg/L, the increase in depth reached on average by this concentration can be calculated. Perhaps the valley of lower concentration for the shallow system evident in both time periods can be explained by physical factors, leading to an important new understanding. Or perhaps the wells sampled at these depths were different in some characteristic, leading the scientist to sample additional wells more like those at other depths. A good graph will provide much more understanding than a table to the audience, whether they are scientists or managers, often leading to new understanding or to better decisions.

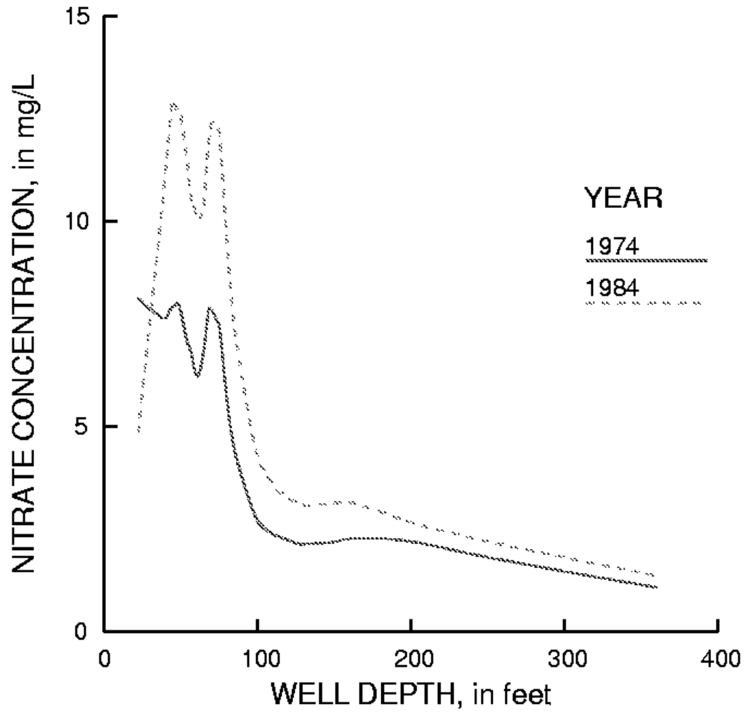

Figure 16.1 Nitrate concentrations in Nebraska groundwater.
Data from Exner and Spalding (1976) and Exner (1985).

16.2 Precision of Graphs

The purpose of a scientific graph is to display quantitative information in a clear and concise manner, illustrating a major concept or finding. During the 1980s research was conducted to determine how easily the human eye-brain system can perform various tasks of perceiving and processing graphical information. The purpose was to rank tasks necessary in interpreting common graphs, such as bar and pie charts, in order to understand which types of graphs are most effective in presenting information. Prior to this time scientists had no objective means of determining which graphs should be preferred over others, and choice was merely a matter of preference.

The primary study was conducted by Cleveland and McGill (1984a). Their major precept was stated as:

> A graphical form that involves elementary perceptual tasks that lead to more accurate judgments than another graphical form (with the same quantitative information) will result in better organization and increase the chances of a correct perception of patterns and behavior (pages 535-6).

They then ranked perceptual tasks on the basis of accuracy, as determined by the number of correct judgments of identical data displayed by different graphs. This ranking is given in Table 16.1. Their concept of accuracy might also be thought of as precision -- smaller trends or differences between data groups can be discerned using more "accurate" tasks. Use of graphs employing tasks higher in table 16.1 will allow smaller differences or trends to be seen. Tasks lower in the table are sufficient to display only larger differences. These lower tasks are those most commonly found in "business graphics", newspapers, and other popular illustrations. Thus when deciding which types of graphs to use, both the precision needed and the expected audience must be considered. When scientists are the main audience, graphs using tasks as high in the table as possible are preferable. When less precision is required to illustrate the main points and the audience is the general public or managers, some of the less precise business graphics may communicate more easily.

More Precise	Position along a common scale
•	Positions along nonaligned scales
•	Length, Slope, Angle
•	Area
•	Volume, Curvature
Less Precise	Shading, Color saturation

Table 16.1 Precision of perceptual tasks (adapted from Cleveland and McGill, 1984a).

16.2.1 Color

Color can both enhance and interfere in the ability to precisely and accurately read graphs. It can interfere in judgments of size between areas of different colors (Cleveland and McGill, 1983). From color theory it is known that "hotter" colors such as reds and oranges, and colors of greater saturation will appear larger than "cooler" colors (blues) and pastels (lesser saturation). Therefore areas shaded a bright red on a map, as is commonly done for computer-map output of pollution studies, will appear larger than they would if shaded another color or with a pastel such as light pink. The eye is drawn to these areas, and their impression is larger than the proportion they would receive by area alone.

Pastels can therefore be used to minimize the biasing effect of both hotter and brighter colors. The low saturation ("washed-out" color) minimizes differences between hotter and cooler shades, and therefore put all areas on an equal footing. Of course this defeats the "newspaper graphics" effect of attracting attention to the graph, but enhances the graph's ability to portray information.

Color can also be quite helpful in presenting data when judgments of size are not being made. When differentiating groups of data on a graph, for example, each group could be assigned a different color, as opposed to a different symbol or letter. Circles or dots of differing colors allow greater visual discrimination than do differing symbols or letters (Lewandowsky and Spence, 1989). Similarly, color lines allow better perception than solid versus patterned lines. As color is not yet widely available in scientific publication media, its best use to date is in presentations at conferences and lectures. Here color can greatly aid the viewers' precision in differentiating points and lines representing data of different groups.

16.2.2 Shading

Figure 16.2 illustrates the most common use of shading -- shaded maps where the density of the ink indicates the magnitude of a single variable. The maps may be of the entire country, a state, or a study area. These "shaded patch maps" or "statistical maps" have inherent difficulties for correct interpretation.

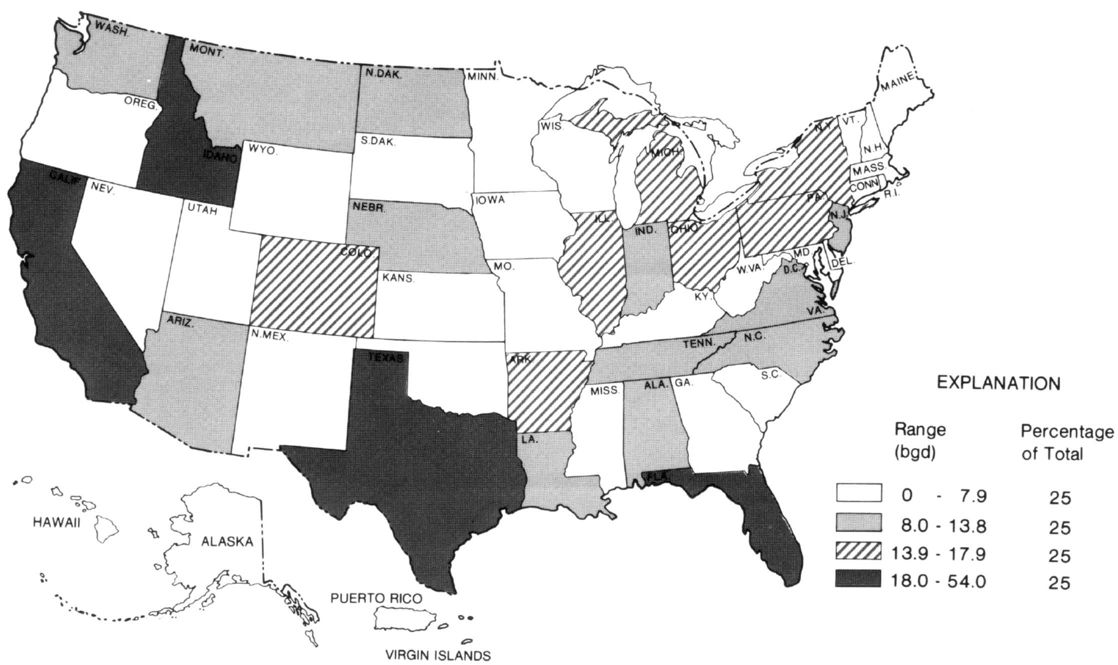

Figure 16.2 Total offstream water withdrawals by state, from Solley et al. (1983).

The first difficulty is that the impression an area makes on the human brain is a function of both the shading and the size of the polygon. Thus larger areas stand out in comparison to smaller areas, though their shading may be equal. In figure 16.2, Texas stands out not only because it is dark, but because it is large. Of the lightly shaded states, the eye is drawn to Montana (MONT) because of its size rather than to New Jersey (NJ). However, an area's importance may not be related to its physical size. If population is important, as it may be for the water withdrawals in each state as shown in figure 16.2, a state with a higher population like New Jersey may be far more important than is Montana, a state with much smaller population. The weighting given to larger areas on a shaded map is often inappropriate to the data being illustrated.

A second limitation is that all variability within areas is totally obscured. Thus a map is only as precise as the size of the areas being shaded. Water use undoubtedly varies dramatically across Texas and other states, but that cannot be shown on a shaded map unless the states are subdivided into counties. Counties vary considerably in size across the country, so that the generally larger counties in the Western U. S. will produce greater impressions on the viewer than do smaller Eastern counties.

Third, only a small number of shading levels can be distinguished on a map. Five shades of grey including black and white can usually be portrayed, but more than five is difficult to distinguish. Differences degrade as graphs are reproduced on a copier. In an attempt to augment the number of classes shown on a map, patterns of lines and cross-hatching are sometimes used, such as the 13.9-16.9 class in figure 16.2. Such patterns quickly become very confusing, actually reducing the eye's ability to distinguish classes of data. One must also be careful to use a series of patterns whose ink density increases along with the data Figure 16.2 seems to violate this rule, as the shade of the second class (8.0-13.8) appears darker than the third striped pattern.

Two types of alternatives to shaded maps are tried. The first type continues to display the geographic distribution on a map, with symbols depicting data classes within each area (each state). Circles or squares with shading or color according to the classification are one possibility. Bars are another possibility (figure 16.3). With bars the perceptual task is a judgment of length without a common datum, an increase in precision in that differences between areas may be distinguished at more than five levels. However it is often difficult to place the bars within state boundaries. Framed rectangles (figure 16.4) are another symbol which may be used within each state. For these the task is a judgment of length along a non-aligned common scale, an improvement in precision over judgments between shadings.

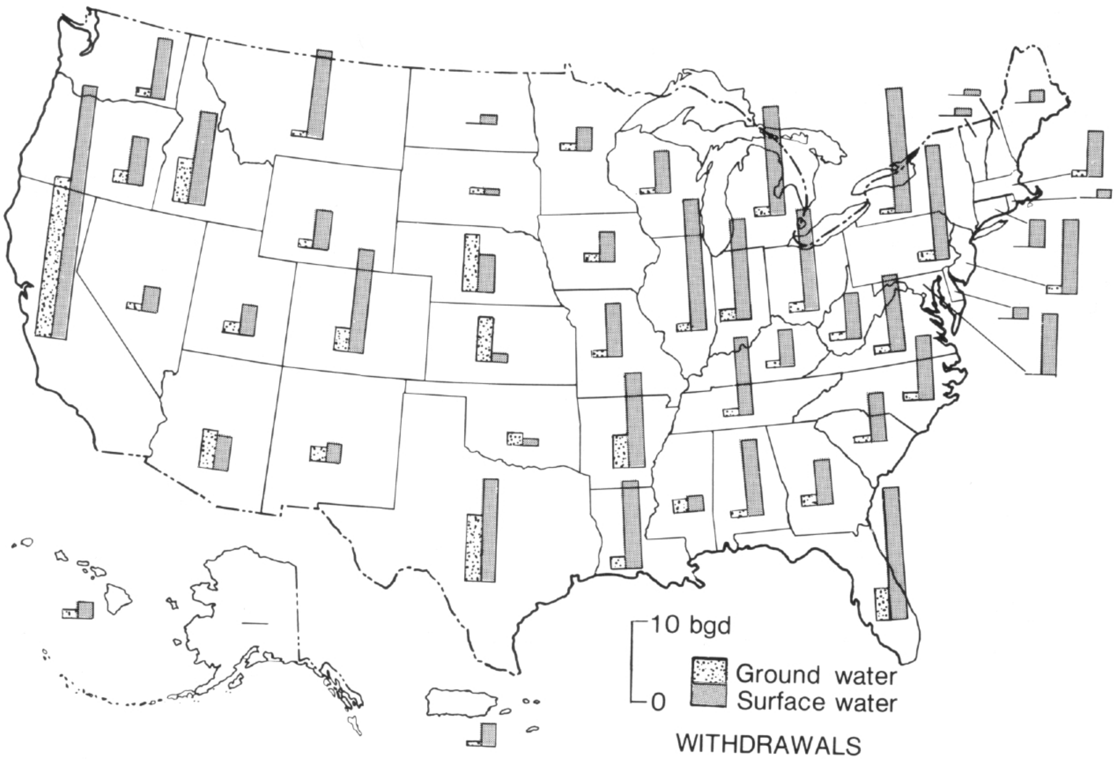

Figure 16.3 Withdrawals for offstream use by source and state, from Solley et al. (1983).

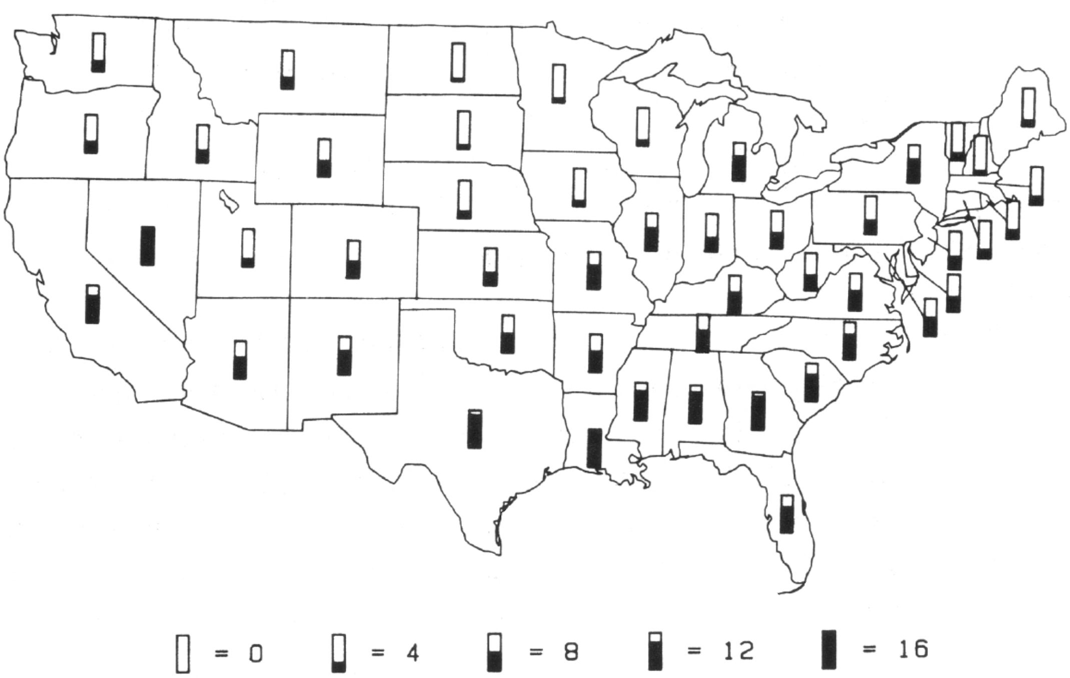

Figure 16.4 Murder rates per 100,000 population, from Cleveland and McGill (1984a).

The second alternative to shaded maps is to abandon a map background, and construct bars or other ratings for each state. These can be classed by region, though much of the regional perspective is sacrificed for state-by-state precision when abandoning maps.

16.2.3 Volume and Area

The most common use of area perception is with pie charts. These graphics are most often used when the sum of data equals 100 percent, so that slices of the pie indicate the relative proportion of data in each class (figure 16.5). However, only large differences can be distinguished with pie charts because it is difficult for the human eye to discern differences in area. In figure 16.5 it is only possible to see that the northeast slice in the lower right part of the pie is larger than the others. No other differences are easy to distinguish.

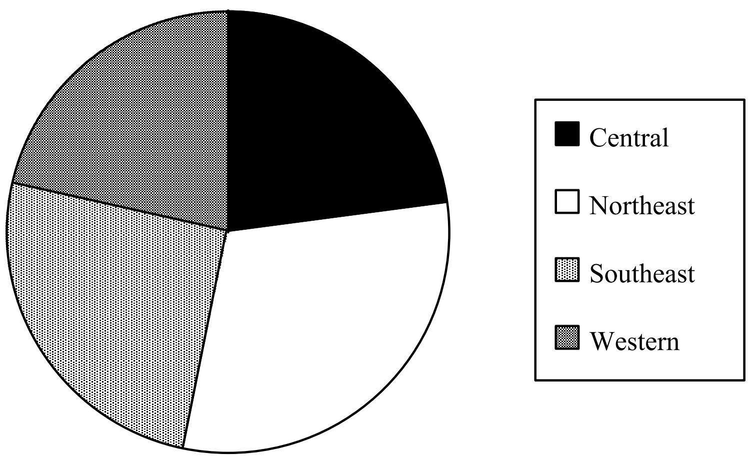

Figure 16.5 Numbers of students from four regions of the U. S.

It is always possible to replace a pie chart with a figure using one of the higher perceptive tasks in order to improve precision. For the same data of figure 16.5, figure 16.6 presents a "dot chart" (Cleveland, 1984), a thin bar graph. Now the judgment is of location along a common scale (the y-axis), and all differences are clearly seen. The four regions can be ordered and estimates of the magnitude for each read from the scale. The data are displayed with much greater precision than with a pie chart.

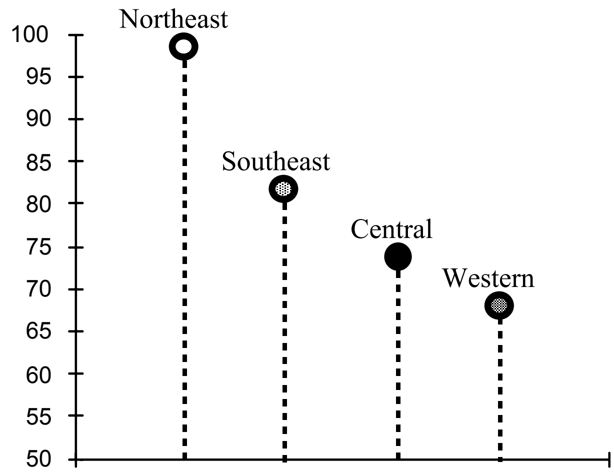

Figure 16.6 Dot chart of the student data of figure 16.5.

Pie charts have little utility for scientific publications, due to their imprecision. The comparison of water quality at two stations in figure 16.7, for example, would be better done using a more precise method, such as two stiff diagrams (see Chapter 2). The presence of numbers on the graph is a clue that the graph is incapable of portraying differences with the necessary precision. It is instead a circular table. Graphs with numbers are often a "red flag", signalling the inadequacy of the graph itself.

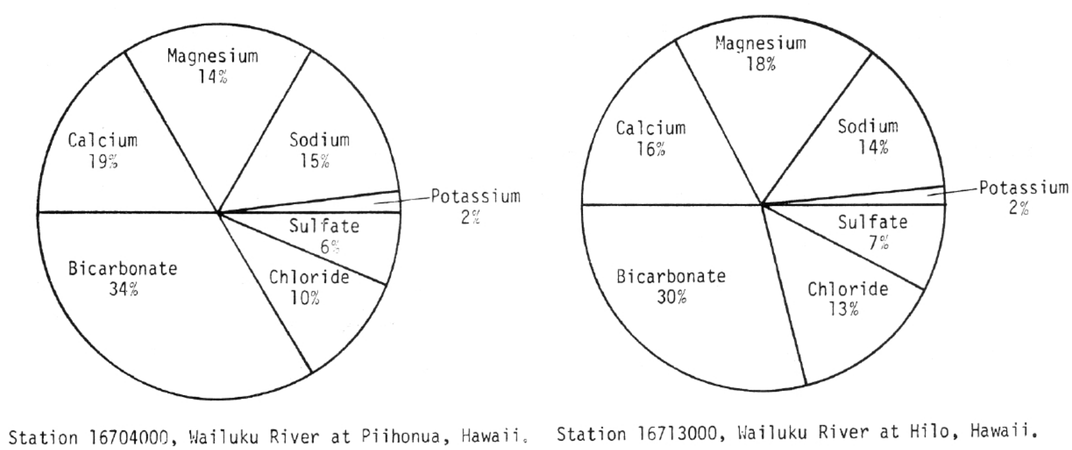

Figure 16.7 Water quality at two sites in Hawaii (from Yee and Ewart, 1986).

16.2.4 Angle and Slope

Judgements of angle and slope occur when comparing two curves, such as in figure 16.8. Differences between the curves are often of interest, and differences are represented as distances in the y direction. However, the human eye sees differences primarily in a direction perpendicular to the slope of a curve, much like the least normal squares line of Chapter 10. We do not naturally see differences as they are plotted. So in figure 16.8 it appears that differences are largest in the center, and smallest at the extremes of X. However, the bottom figure shows the differences directly. The largest differences are on the left, with a linear decrease as X increases! To truly see differences in the top figure a judgment is required about the angles of the lines in relation to the y axis, and this is quite difficult. A good rule of thumb is that if differences are of interest, plot the differences directly.

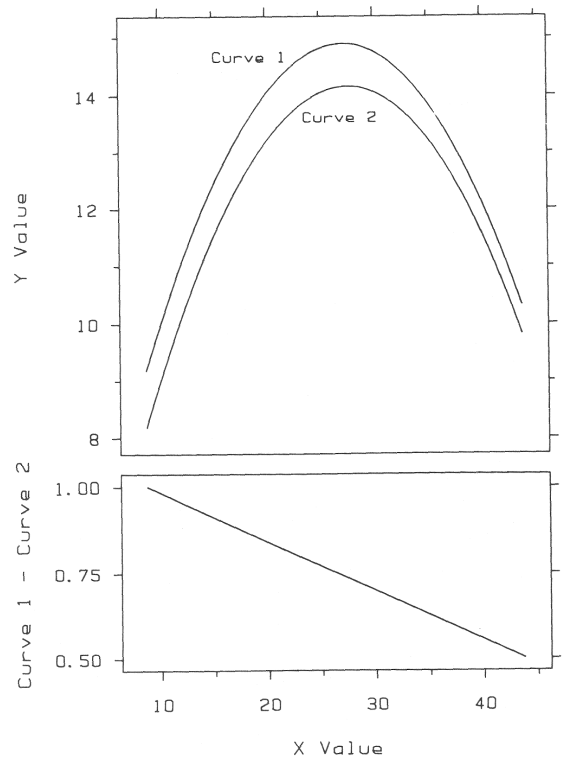

Figure 16.8 Comparison of two curves. From Cleveland and McGill (1985).

Figure 16.9 is a comparison of measured and model logarithms of streamflow. Which days show the poorest predictions? Though it appears that the largest difference in log streamflow occurs on May 16 and in latter June, the mismatch is actually much greater on and near May 6. If the purpose of the graph is to portray daily differences, the differences themselves should be plotted.

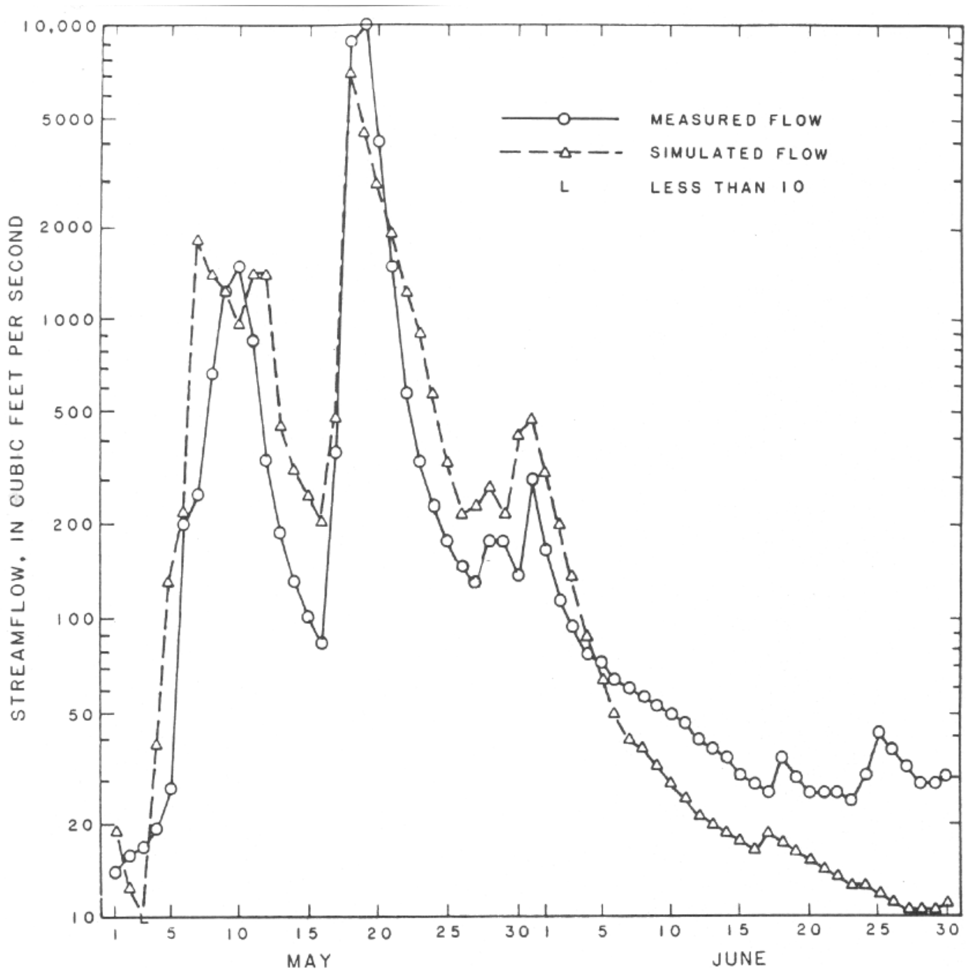

Figure 16.9 Measured and simulated streamflow. From Bloyd et al., 1986.

Another type of graph which uses judgments of slope and angle is a cumulative line graph such as figure 16.10. A quick look at the graph might indicate that x2 and x3 are increasing, simply because their baseline is increasing. To determine the magnitude of any variable except the one whose base is the x-axis requires compensating for the non-horizontal baseline angle as it changes across the range of X. This is obviously difficult to do. The determination of which of the three items in figure 16.10 is largest in periods 1 and 2 is also quite difficult, for example.

One justification for cumulative line graphs is that they show the proportion of values against the total, which is shown as the top line. Moving up the table of perceptual tasks results in a better solution -- to plot each of the variables separately, and plot the total if it is important. This is done in figure 16.11. Determination that x3 is either equal or greater than the others during periods 1 and 2 is much easier here. The cyclic variation of x3 is also easier to spot. Comparisons between variables with small magnitudes such as x2 and x3 are not swamped out by larger variations in the variable at the base (x1). Judgements are made using position along a common scale (the y-axis), a much easier and more precise task than in 16.10.